Digital cinema projection: choosing the right technology

By: Alen Koebel

It’s always good to have choices.

Today, when deciding on which digital cinema projection system will best serve the needs of your business and the expectations of your customers, you have more choices than ever. First, you have a choice between projection technologies; two today and potentially more in the future. You can choose between two approved pixel formats (resolutions). You have a choice of technologies for 3D, a high value add-on for digital cinema projection. And lastly, you have a choice of vendors.

Not all of these choices are independent. And it’s not always apparent which of them is right for a given theater. To clear up the confusion, this whitepaper will discuss the relevant technologies, their fundamental differences and show how they impact the factors that are most important for theatrical exhibition: image quality, functionality, reliability and cost of ownership.

What makes a good image?

What makes a motion-picture image look good? Technically, projected images can be defined by a number of different parameters such as brightness, contrast, color space, color depth, resolution, device refresh rate and, for motion pictures, temporal resolution. The subjective evaluation of an image as “good” or “poor” is based on the overall effect of all of these parameters working together.

Nevertheless, resolution in particular is often sold as the most important parameter. However, most people would agree that a dim, washed-out image with poor colors, as an extreme example, wouldn’t look good no matter how sharp. Everything else has to be in place for resolution to make a difference. Not all projection technologies are equally adept at getting everything right.

Counting pixels

Since resolution has garnered so much attention, let us examine it in detail. Resolution is often equated with the pixel format of the display device, hence it is said that the resolution of a “2K” projector is 2048 x 1080 while that of a “4K” projector is 4096 x 2160. However, a display’s pixel format is not the same as its resolution. The pixel format tells you only how much information an image can contain, whereas resolution tells you how much of that information is actually conveyed to the screen and can (potentially) be seen by the audience.

Resolution depends on both the projection technology and on the capabilities of the human visual system (hereafter HVS) in a theater environment.

With respect to the HVS, optometrists commonly use the Snellen eye chart (Figure 1) to determine approximate visual acuity based on the finest line of text that can be read from a certain reference distance. Normal acuity is identified as 20/20 (or 6/6 in metric), signifying that a specific line on the chart can be read at a distance of 20 feet (6 meters). The finest details of the letters on that line (e.g., the strokes in the letter E) are one angular minute of arc wide, or 1/60th of a degree. If the chart were presented as a digital image using discrete pixels, 20/20 vision would then equate to resolving 60 pixels per degree.

However, “resolving” in this context means only that we can identify a letter made up of pixels. To clearly see the shape of each pixel (whether it is a square or a round dot, for example), or any separation or gap between adjacent pixels that may exist, would likely require even greater visual acuity.

This is important in the context of digital cinema, since all currently practical projection technologies use square pixels with a small inter-pixel gap.

Brightness is also a consideration. In the Snellen test the chart should be adequately illuminated, such that the minimum luminance of the white background is 120 candelas per square meter (cd/m²) [1].

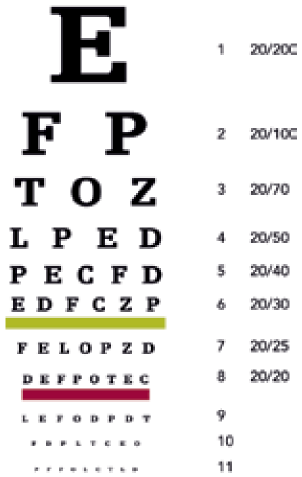
This ensures dilation of the eye’s pupil to about 3mm, resulting in maximum acuity [2]. The nominal luminance of peak white specified for digital cinema images, on the other hand, is only 48 cd/m², more commonly expressed as 14 foot-lamberts (fL) [3]. Combined with the effect of a dark surround, this results in a pupil dilation in the range of 4-6mm [2]. Because optical aberrations increase with lens aperture, this causes a roughly 30% drop in visual acuity, equivalent to 20/28 vision or about 42 pixels per degree [4].

However, some studies have suggested that normal visual acuity could be as low as 44 pixels per degree, which in a darkened theater environment becomes just 32 pixels per degree [5].

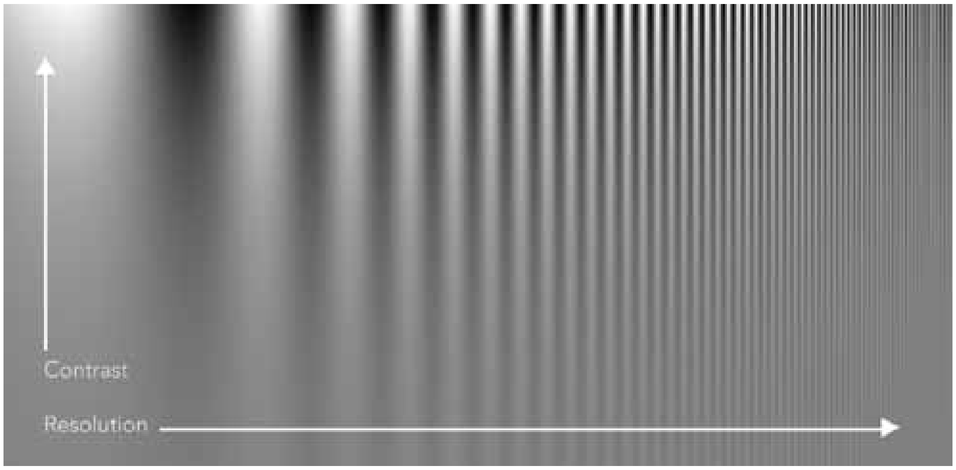
Note that the above numbers apply only to a predominantly white image containing black text, like the Snellen chart. The average luminance of most real images in a movie, which contain a mix of colors and gray levels, is far lower, resulting in pupil dilations at the large end of the range and hence, even less acuity. Very dark scenes in particular may cause the HVS to approach or even enter the “mesopic” region, in which it is more sensitive than normal to light, but with less color discrimination and with far less acuity.

Looking sharp

Regardless of what specific acuity number applies while watching a movie in a theater, it tells us only about the finest details we can resolve. As it turns out, due to another property of the HVS the finest details do not contribute much to our perception of sharpness. A relationship called the Contrast Sensitivity Function (Figure 2) describes how different spatial frequencies (the rate at which light and dark lines alternate) are seen with different amounts of contrast. We see details most clearly – that is, with the greatest



▲ Figure 1
Typical Snellen Eye Chart



▲ Figure 2
Contrast Sensitivity Function

contrast – in a range between 4 and 9 line pairs line per degree, equivalent to between 8 and 18 pixels per degree [6]. An image that reproduces spatial frequencies in this range with high contrast will look sharp. Higher spatial frequencies in the image contribute significantly less to that perception.

To understand the affect of contrast sensitivity, we must examine seating distances in a theater. Despite different screen sizes, the distances of seats from the screen in today's stadium-seating venues vary over a remarkably similar range when expressed as multiples of screen height. The closest seats are usually a little less than one screen height away, while the farthest are somewhat closer than three screen heights (Figure 3).

From one screen height away, the screen will span 53 degrees of our vertical field of view. Horizontally, it will be anywhere from almost 100 degrees to nearly 130 degrees, well beyond what most viewers prefer to experience. Choosing the more demanding end of the range of spatial frequencies that are important for sharpness – 18 pixels per degree – results in a minimum requirement of 956 vertical pixels (pixel rows). In the horizontal direction, a flat (1.85:1) picture would require a minimum of 1769 pixels. (For scope, the requirements will depend on whether the screen is constant width or constant height.) If the pixel-to-pixel contrast is very high for the most important spatial frequencies, an image with these pixel dimensions or greater will look sharp.

This conclusion is consistent with the subjective experiences of countless theater patrons viewing DLP Cinema® images over the past several years. The 2K images from these projectors, which fit within a full-frame image "container" of 2048 x 1080, do indeed look sharp, even from the front row of the theater. This wouldn't be possible were it not for the high performance of DLP® technology itself, which provides the extremely high pixel-to-pixel contrast required.

I see pixels

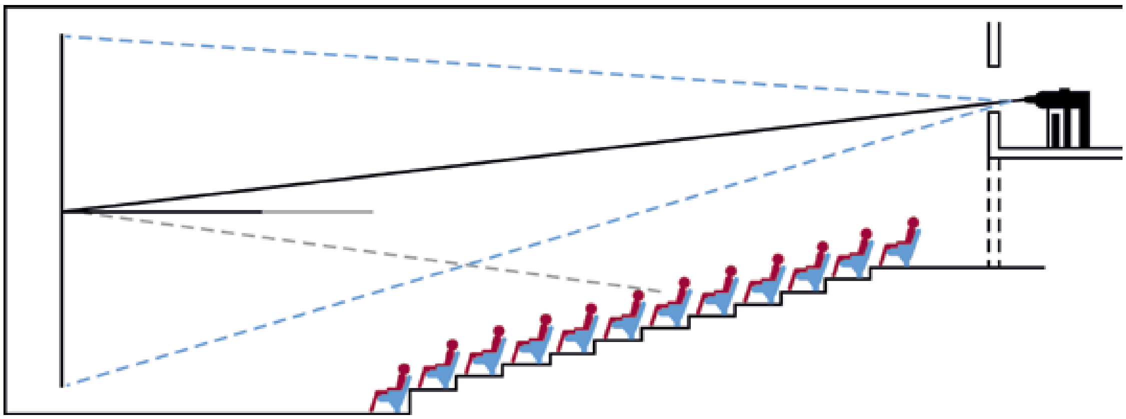
What then of 4K? As we have seen, it is not necessary for achieving sharp images since even 2K projection provides sufficient resolution, assuming the use of DLP technology. The primary advantage of 4K is, rather, the reduction it offers in the visibility of pixels, an issue that is entirely different than resolution. For certain images (the closing credits of a movie, for example) viewers seated in the first few rows of a theater can easily detect the square shape of the pixels in a 2K image of characters as they roll up the screen. The closest seats have traditionally always been the least desirable for most patrons, since viewing angles are overly wide and neck inclinations are severe. In the case of a 35mm presentation, film grain is also much more obvious. However, because of its random nature film grain may be less objectionable to viewers than a static pixel structure.

A 4K image has twice as many pixels in both the horizontal and vertical directions as a 2K image, which results in four pixels in the space a single pixel occupies in a 2K image. Since the pixels are half the size in each direction they are proportionally harder to detect. This becomes more important for wider screens, since the increased width of the theater places more seats closer to the screen.

One argument made for 4K is simply that it has far more pixels than 1080p high-definition televisions. Why would patrons come to a theater to see almost the same number of pixels they can watch at home? This once again incorrectly equates image quality to a single parameter: pixel count, and it conveniently ignores the fact that digital cinema images are far, far better in other, more important respects than even the best home video formats (e.g., Blu-ray Disc™).

Compared to Blu-ray Disc, digital cinema images have a wider color gamut, four times the color information, up to sixteen times finer gray shade resolution and have been compressed far more lightly with a compression scheme that inherently creates less visible artifacts (JPEG 2000).

Another essential difference between cinema and home theater is that very few homes are likely to have a 20-foot wide or larger screen (most are less than four feet wide). The argument that sitting proportionally closer to a smaller screen is equivalent to viewing a large screen in a cinema ignores the fact that our inter-ocular distance does not change – we sense the screen's real size and distance.



▲ Figure 3
Typical stadium seating auditorium where the front row is just under 1 screen height from the screen and the last row around 3 screen heights from the screen

Projection technologies

Ultimately, the choice of projection technology has the greatest affect on image quality, as well as on other factors important to theatrical exhibition, including functionality, reliability and cost of ownership.

Two projection technologies are used today for digital cinema: LCoS (Liquid Crystal on Silicon) and DLP. These are also used commonly for other projection applications, where they are joined by LCD (Liquid Crystal Display). LCD, however, has not measured up to the demanding requirements of digital cinema and no LCD projectors are currently certified for playing Hollywood studio content. The same is true for alternate technologies such as GLV (Grating Light Valve) and scanning laser projection, which today see very limited use and are not yet capable of the light levels required for digital cinema at a price anywhere close to being affordable. DLP and LCOS projectors that use lasers as light sources are expected to be more viable, however they will face some of the same issues discussed in this article.

LCoS and DLP are fundamentally very different technologies. LCoS works by impressing a voltage proportional to a desired gray level across a very thin layer of liquid crystal material to control the polarization of light generated from the light source. In cinema applications the light source is nearly always a Xenon arc bubble lamp. In an LCoS device (Figure 4) the liquid crystal layer is sandwiched between a transparent glass electrode on one side and what is essentially an integrated circuit with an aluminum mirror as a top layer on the other. After passing once through the liquid crystal layer, the light reflects off the mirror and passes through the layer again, going in the opposite direction (Figure 5). To create images, the device is organized into a rectangular array of pixels that are individually addressed using a series of row and column electrodes that are hidden beneath the mirror layer.

DLP is based on an entirely different principle. Thereis no liquid crystal layer. Instead, light from the lamp directly hits and reflects off an array of extremely tiny, aluminum mirrors on top of an integrated circuit, one mirror for every pixel in the image (Figure 6). Each mirror is individually addressed, not by an analog voltage proportional to pixel intensity, but by a single digital bit. In the "1" or "on" state, a mirror tilts over at an angle, directing the light out the projector's lens to the screen. In the "0" or "off" state, the mirror tilts in the opposite direction, directing the light to a light absorber (Figure 7). This produces peak white or pure black, respectively. To generate gray levels between, the mirrors are flipped between the on and off states thousands of times a second. At that rate the resulting individual pulses of light seem to merge completely and we see only an average light level proportional to the ratio between the on and off times.

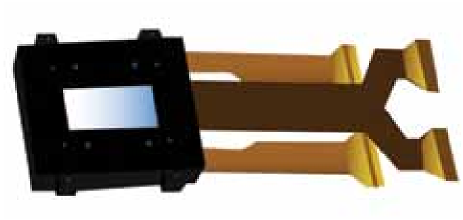
LCoS and DLP projectors for digital cinema achieve color images by splitting white light from a Xenon high-intensity discharge lamp into red, green and blue components and directing them to individual devices, one for each component color. A prism assembly overlays the three resulting component images into a full-color image for projection onto the screen.

LCoS vs. DLP

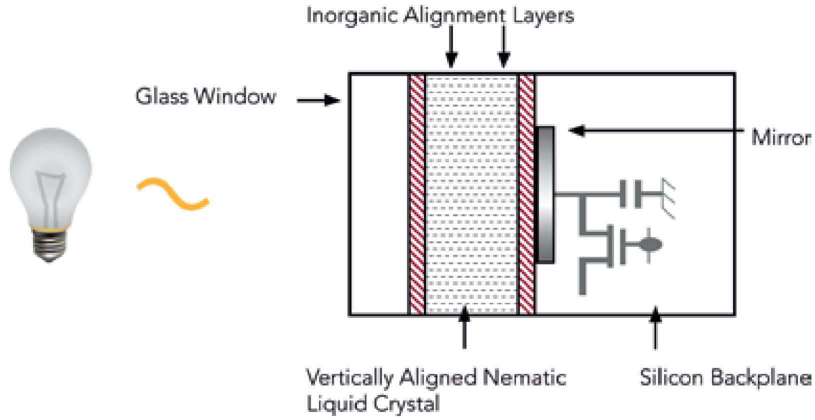
The fundamental differences between LCoS and DLP directly affect the design of digital cinema projectors, leading to significant differences in some very important performance parameters. The first parameter affected is optical efficiency. This primarily affects the lamp power required to achieve the image brightness specified by SMPTE (Society of Motion Picture and Television Engineers) on a screen of a given size [3]. Lower optical efficiency means higher power, which increases operating costs due to higher electricity consumption and more frequent lamp changes (as well as a higher unit cost on the lamp itself if a larger wattage lamp is required). It also puts a limit on the largest screen size a projector can support, which becomes an even greater issue for 3D (more about this later).

For example, based on published specifications Sony's SRX-R320 projector, which uses a proprietary version of LCoS called SXRD™, outputs 21,000 center lumens using a 4.2 kW lamp [7]. The optical efficiency is thus 5 lumens per watt. In comparison, the Christie® CP2220 DLP Cinema projector, using a much less powerful 3.0 kW lamp, can output as much as 22,000 center lumens, which is an optical efficiency of 7.3 lumens per watt. This is nearly a 50% advantage for DLP technology. Measurements of actual projectors operating in theaters suggest the true advantage may be closer to 100% in favor of the Christie CP2220.

Uniformity across the image is another area in which LCoS and DLP perform quite differently. This is directly due to the nature of the devices. LCoS is fundamentally an analog technology, in which gray levels are



▲ Figure 4
LCoS (Liquid Crystal on Silicon) device



▲ Figure 5
Light path through an LCoS device

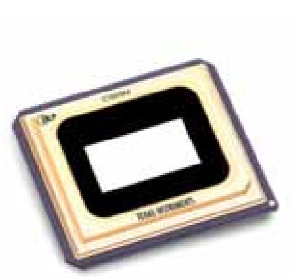
proportional to a voltage. (LCoS is digital only in the sense that the image is composed of discrete pixels.) The voltage required for a given gray level depends primarily on the electro-optical properties of the liquid crystal layer, which can vary across the device. These properties are also affected by environmental conditions, in particular temperature. The liquid crystal heats up as it inevitably absorbs some of the extremely high intensity light passing through it in a digital cinema application. This can cause significant non-uniformities and color shifts in the image.

Unlike LCoS, DLP is a truly digital technology. Pixels are binary; they are either on or off. Gray levels are achieved by varying the timing between on and off. Not only is this highly reproducible, the timing required for a given gray level is not sensitive to temperature or other environmental conditions. Hence, gray shades and colors are inherently stable and uniform across the device. Achieving similar performance with LCoS is challenging. Careful, on-site calibration appears to be required, which should be done periodically. Sony offers an optional, CCD-camera-based system that automates the process.

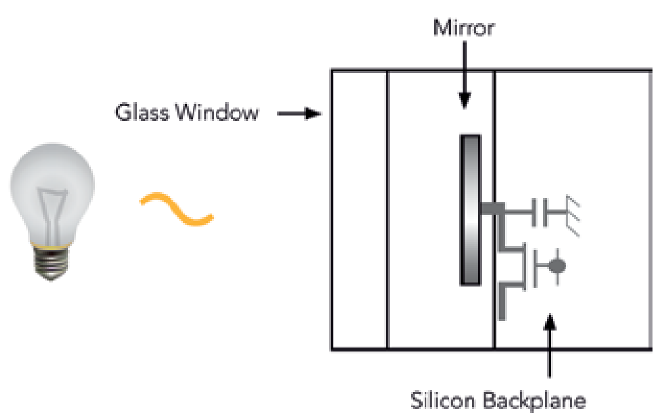
It is noteworthy that DLP Cinema technology was recognized by the Academy Board of Governors who bestowed the A.M.P.A.S.® Scientific and Engineering Award* in 2009 for color accurate digital intermediate previews of motion pictures.

Reliability is another important issue. After many years of operation, DLP has an admirable track record. For example, Christie's DLP Cinema projectors have an uptime ratio of 99.999% as determined by network monitoring of thousands of installed projectors over a period of several years [8]. The reliability of LCoS projectors is harder to establish, since Sony has not published reliability data (as of this writing). Perhaps this is simply because far fewer sites have been operating long enough to gather meaningful statistics. However, the problems Sony has experienced with consumer SXRD products may be cause for concern [9].

One of the realities of Hollywood approved digital cinema today is that there are three manufacturers of DLP Cinema projectors, but only a single manufacturer of LCoS projectors, resulting in more choices on the DLP side. The DLP Cinema brand also assures a measure of interchangeability and a high degree of interoperability with other equipment in the theater. The latest generation of DLP Cinema projectors continues this philosophy, allowing third-party vendors to design Image Media Block products that install inside the projectors, all based on a common specification. Sony's solution, in contrast, is entirely proprietary.



▲ Figure 6
DLP device



▲ Figure 7
Light path to a hinged pixel on a DMD (Digital micromirror device)

*Recipients of the Academy Plaque are D. Scott Dewald, Greg Pettitt, Brad Walker and Bill Werner.

3D technologies

Stereoscopic 3D is a major catalyst for digital cinema. Attempts to bring it to theaters in the early 1950's and again in the early 80's were thwarted by the practical limitations of film projection. Today, digital cinema technology has allowed a true 3D renaissance, making it more practical for general theater exhibition than ever before.

You have many choices for adding 3D to a DLP Cinema projector, with current offerings from Dolby, MasterImage, RealD, XpanD and Panavision. All of them share the technique of rapidly alternating between left-eye and right-eye images. They differ in how they ensure that each of those images gets to the correct eye.

The RealD and MasterImage systems employ devices unique to each that, when placed in front of the projection lens, change the polarization of light between the left-eye and right-eye images. Viewers wear passive (non-powered) glasses that direct one polarization state to the left eye and the other polarization state to the right eye.

In contrast, the Dolby and Panavision systems employ a color filter wheel inside the projector that changes the color gamut between left- and right-eye images. The passive glasses viewers wear are essentially sophisticated color filters.

The XpanD system differs in that it does not change the images leaving the projectors. Rather, the glasses act like shutters, actively switching between the left and right eyes, alternately blocking the view of one while opening the view of the other.

The choice of one system over the other may depend on how practical implementation differences affect your business. The RealD and MasterImage systems require silver screens, while Dolby, Panavision and XpanD do not. (However, since all 3D systems benefit from a higher gain screen than normal, a new screen may be beneficial in any case.) The glasses used by RealD and MasterImage are inexpensive enough to be given away to patrons. The Dolby, Panavision and XpanD glasses are relatively expensive, so they are typically collected and washed between uses.

All of the 3D systems for single DLP Cinema projectors switch between left-eye and right-eye images at 144 frames per second (Figure 8), a technique known as "triple flash." Sony's SXRD is not fast enough to do this, despite being one of the fastest implementations of LCoS available.[1] Consequently, none of the systems described above will work with current SXRD cinema projectors.

One technique that does work, however, is to display the left-eye and right-eye images together in the same image, one positioned above the other (known as "over/under"). A complicated optical adapter then projects and overlays the two images onto the screen, where they are viewed with RealD polarizing glasses (Figure 9). This approach leads to a number of compromises.

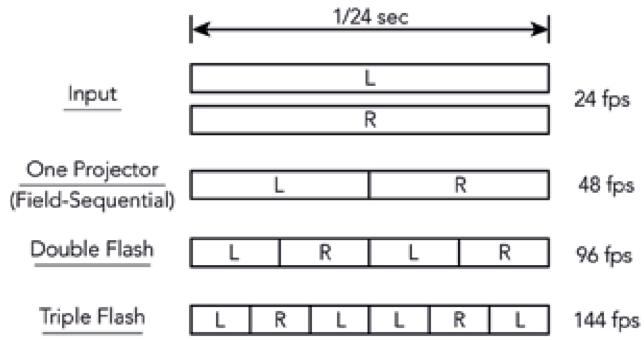
The first compromise is to light output. Despite heroic efforts to recover light that would otherwise be thrown away, a 3D image appears through the glasses to be, at best, only 18% as bright as a 2D image from the same projector on the same screen, based on Sony's own published numbers. RealD's XL system for DLP Cinema projectors, in comparison, is at least 50% more efficient [11]. Coupled with the superior optical efficiency of DLP Cinema projectors, which can output over 30,000 lumens, this allows DLP Cinema to support much larger 3D screens than LCoS technology based projectors from Sony.

The second compromise is to resolution. Paradoxically, the 3D image from a 4K SXRD projector could easily appear less sharp than a 3D image from a 2K DLP Cinema projector.

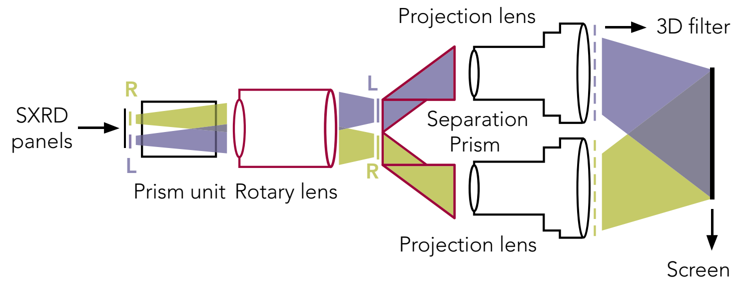
Each eye's image starts out in a 2K format from the server. However, flat (1.85:1) images need to be resized to fit on the LCoS device for proper display through the 3D optical system – in practice, scope (2.39:1) images are also resized for another reason. Resizing can degrade the image, especially when it reduces the pixel count as happens in the 1.85:1 case. The complex optics that project left-eye and right-eye images using separate lenses and overlay them on the screen can further degrade the image, if extreme care is not taken during alignment.

The 3D adapter will also greatly impact 2D presentations if it is not removed for 2D showings. Since alignment is so tricky, there is a natural temptation to leave the adapter in place and simply remove the polarizers, which effectively turns a 4K projector into a poor 2K projector with much reduced brightness.

[1] Triple flash frames change at a rate of one every 7ms. For an acceptable level of crosstalk between left-eye and right-eye images the device must respond much faster. Currently, SXRD projectors require nearly 2.5ms to change the state of a pixel, which is more than 33% of the triple-flash frame time and hence unsuitable [10].



▲ Figure 8
"Triple Flash" 3D

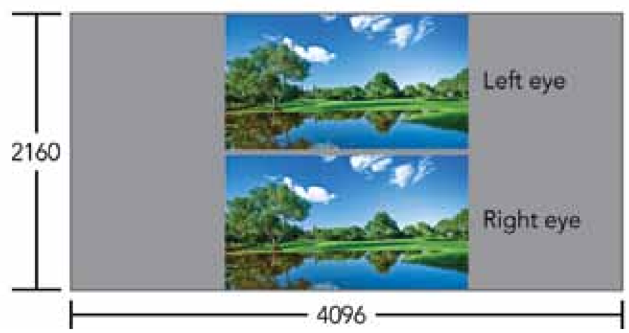


▲ Figure 9
Sony SXRD "Over / Under" 3D Optical System

Conclusion

Which digital cinema projection technology will best serve the needs of your business and the expectations of your customers? Making that determination requires examining all aspects of performance with respect to image quality, functionality, reliability, and cost of ownership.

For more information, please contact Christie at christiemarketing@christiedigital.com.



▲ Figure 10
Flat left-eye and right-eye images must be resized for the over/under format.

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As a senior design quality specialist in Christie's Global Quality department, Mr. Alen Koebel is responsible for developing and promoting world-class design practices and procedures within Christie. Alen's role involves reviewing product designs, developing test and measurement methodologies and promoting the principles of lean product development.

Alen's product design experience ranges from early, all-analog CRT projectors to high-powered, all-digital DLP Cinema projectors. Alen has been directly involved in the design of many of the company's major product lines including a role as a system architect for the industry-leading CP2000 family of DLP Cinema projectors that started the on-going conversion of cinemas to digital projection.

Alen is a member of the Society for Information Display. He is also a Contributing Editor for Widescreen Review magazine, a well-respected publication for the home-theater market.

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